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AN EVALUATION OF THE PROTECTIVE DEVICES' BOMB HANDLING SYSTEM

by
James A. Frigiola

MARCH 1973

NAVAL EXPLOSIVE ORDNANCE DISPOSAL FACILITY
INDIAN HEAD, MARYLAND 20640

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MARCH 1973

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NAVAL EXPLOSIVE ORDNANCE DISPOSAL FACILITY
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FOREWORD

The test program described herein was conducted by the Research and Development Department of the Armed Forces Explosive Ordnance Disposal Technology Center at the Naval Explosive Ordnance Disposal Facility at Indian Head, Maryland. The work was carried out as part of an interagency program entitled Improved Bomb Neutralization Systems. Funding was provided by the U.S. Department of Justice Law Enforcement Assistance Administration under Interagency Agreement Number LEAA-J-IAA-028-1 (Order Number 1-0837-J-LEAA) of 12 March 1971.

The Improved Bomb Neutralization Systems Program is comprised of a number of on-going projects seeking better methods of dealing with the threat posed by clandestine bombs. One of the methods under consideration is the use of special equipment for controlled venting and fragmentation shielding to minimize personnel injury in case of detonation.

This report covers testing of a bomb handling system which is offered commercially by the Protective Devices Corporation of Costa Mesa, California. The system centers around a bomb basket constructed of laminated fiber glass. The bomb basket is supplemented by hand-carried personnel shields, body armor, and helmets. The tests conducted by the Naval Explosive Ordnance Disposal Facility (NAVEODFAC) involved detonation of a variety of explosive charges and devices so that the protective capability of the bomb handling system could be measured.

EDWARD W. RICE
Head, Research & Development Department

Approved and Released by:

LIONEL A. DICKINSON
Technical Director

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ABSTRACT

The detonation of an explosive device causes injury to personnel and damage to material through two distinct modes: blast overpressure and solid objects which become missiles. The manufacturer of the Bomb Handling System (BHS) claims that it offers protection in both areas. To quantitatively determine these characteristics a series of tests were conducted to obtain blast pressure data from TNT reference charges with and without the bomb basket. Blast pressure attenuation and redirection capabilities were evaluated. Pipe bombs with various bursting charges and improvised explosive devices (IED's) containing dynamite were also detonated as representative fragmentation-producing devices. These tests yielded data on the fragmentation hazard reduction capabilities of the bomb baskets, shields, and body armor. IED's having various size charges were used so that a qualitative idea of the baskets' practical strength limitations could be obtained. In addition, a bomb basket endurance test was conducted using a number of consecutive small charges. This permitted an evaluation of the strength integrity of the bomb basket material.

High speed and still photographs were taken throughout the testing procedure for documentary purposes. Pressure gage data were displayed by dual trace oscilloscopes and photographically recorded. These measured pressures were then compared with standard tabulated values. Plywood fragmentation witness panels were positioned around the bomb basket for each detonation of a fragmentation-generating device. The witness panels were examined after each test and partial and complete penetrations of the plywood were counted and marked.

The bomb baskets, shields, and body armor were seen to have a measurable blast attenuation capability. The multi-ply fiber glass walls of the basket were capable of stopping low energy fragments resulting from the detonation. The shields and body armor provided substantial protection from fragments which first passed through the basket walls.

INTRODUCTION

1. OBJECTIVES

The objectives of this series of tests were twofold. The first objective was to measure the ability of the bomb basket to reduce blast overpressure by directional venting of the explosion. Information was desired which would reveal shock wave behavior as a function of distance and position relative to the basket. This information was considered of critical importance since the BHS will often be used within the confines of a building. The second and equally important objective was to determine the degree of protection from fragmentation offered by the BHS. Pipe bombs, filled with a variety of explosives, were selected for testing because of their fragmentation characteristics. Sheets of 1/2-inch-thick plywood were positioned to act as witness plates around the bomb basket. Fragment impacts were evaluated for total number and approximate severity (whether causing partial or complete penetration). In addition, it was desired to test the hand shields and body armor, when positioned at typical distances from the basket, for their ability to resist fragment penetration. Also of interest was whether the shields and body armor offered any further protection from blast pressure.

Information relative to protection from injury was of primary concern in these tests. The BHS is intended for use specifically as safety equipment and is recommended only for reducing the probability of injury; no claim is made by its manufacturer that users will not be injured. However, an attempt was made to determine how large an explosive charge could be detonated without indications of obvious overdestruction. It is understood that destruction of the basket does not mean that the BHS failed to protect its users. Recommendations for use of the BHS should be made on the basis of estimating the hazard potential as seen from the body armor, rather than the condition of the bomb basket. A final point of interest was whether the basket could be reused after the detonation of a small bomb which caused no apparent damage. Information on the bomb basket endurance capability could contribute to user confidence.

2. BACKGROUND

The BHS was developed as an approach to the problem posed by clandestine bombs. The system is being sold commercially as safety equipment. Law enforcement agencies and commercial airports have thus far shown the greatest interest in the equipment.

The manufacturer of the BHS indicates that it should be used for transporting a clandestine bomb or an IED from the location of discovery to a safe area. In actual cases, the bomb may be carried and transferred to a larger and stronger vehicle-mounted bomb container. It is intended, however, that the BHS be used for the initial movement and transportation. Such use requires two men who will need to be in the close proximity of the bomb for several minutes. Past experience has shown that these initial steps of a bomb disposal procedure usually take place within a building. The purpose of the BHS is to provide personnel protection in case the bomb explodes while it is being moved. The bomb basket is constructed of 16 laminations of woven fiber glass. There is a nylon net which hangs about halfway down inside the basket to suspend and center objects which are placed in it. When an explosion takes place, the blast is vented upward so that the shock wave radiating toward the side is substantially reduced. In addition, any solid objects which become missiles as a result of the explosion must pass through the bomb basket walls before they can strike and injure personnel. The material of which the basket is constructed is bulletproof (capable of stopping .38 and .45 caliber bullets). The BHS includes hand-carried fiber glass shields which offer additional protection from fragmentation. Also included are helmets with face shields and front and back body armor.

The tests described in this report were conducted so that evaluations of the BHS and recommendations for its use, based on unbiased technical data, could be made available to the agencies and organizations wishing to use the equipment.

3. OVERALL APPROACH

Information of two distinct characteristics was sought: the ability of the BHS to redirect blast pressure waves, and its ability to reduce fragmentation hazards.

Piezoelectric pressure gages were used to monitor the high amplitude, short duration pressure pulses which radiate from explosive charges when detonated. Oscilloscopes were used to display the output from the pressure gages and Polaroid cameras were used to record the display. A total of 24 points around the charge, ranging from 20 feet horizontally and 9 feet vertically (see Figure 1, page 3), were selected for pressure measurement. One-pound TNT reference charges were detonated in the closed-bottom basket and in free air (without bomb basket) so that a direct comparison of the blast pressures could be made.

An assortment of pipe bombs and IED's were detonated as fragmentation-producing devices. The body armor and shields were positioned at 6- and 12-foot distances from the bomb basket. Half-inch-thick sheets of plywood were placed around the basket in a semi-circular "fragmentation arena" so that fragment impacts could be observed and analyzed. During the fragmentation tests pressure gages were placed at 6- and 12-foot distances to determine whether the body armor offered any additional protection from blast pressure. Still photographs and high-speed motion pictures were taken for documentation purposes.

TECHNICAL DISCUSSION

1. HARDWARE DESCRIPTION AND USE

In order to measure the blast pressure or peak dynamic overpressure resulting from the detonation of TNT charges, a number of wooden stands were constructed. The wooden stands (8 to 10 feet tall) were positioned at distances of 3 to 20 feet from the center of the bomb basket. Susquehanna "side-on" type, piezoelectric pressure transducers (Model ST-7) were secured to the stands using nails and tape. An equipment trailer containing four dual-trace oscilloscopes was parked a safe distance from the point of detonation. Since only eight signals could be monitored for each shot, it was necessary to detonate three separate charges to get the desired 24 data points. A ninth pressure gage was used at a distance of less than 3 feet to serve as a triggering gage. Several hundred feet of shielded cable were used to connect each pressure gage to the oscilloscopes. The blast wave reached the triggering gage first, which initiated the first oscilloscope's single sweep. The second, third, and fourth scopes were triggered by the first. In this manner the output signal from each pressure gage was displayed at the proper time interval. Polaroid cameras mounted on the oscilloscopes photographically recorded each signal sweep and pressure pulse.

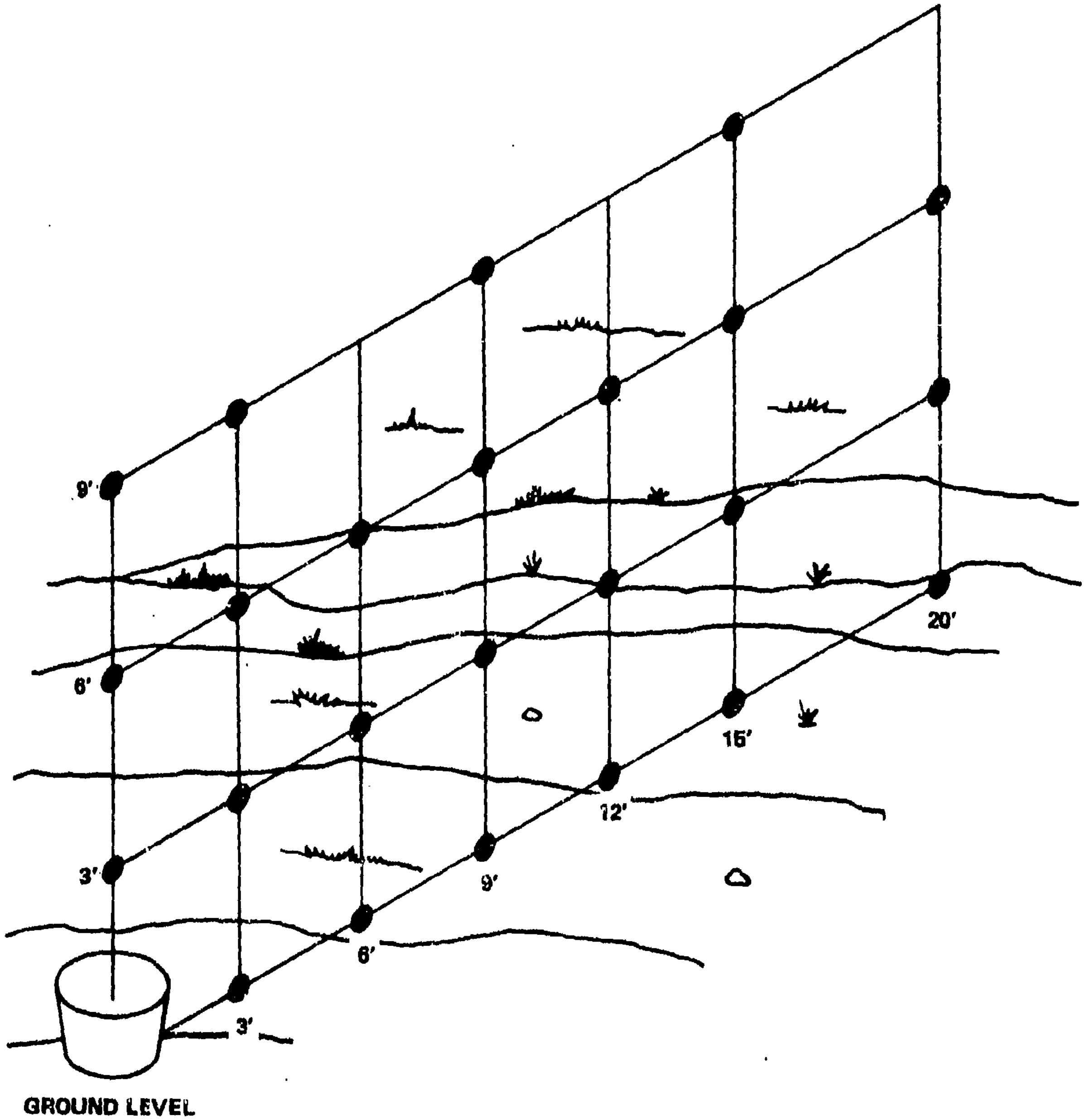


Figure 1. Pressure gage array used for blast pressure measurements in test Shots 4 through 9.

For fragmentation tests the bomb baskets were placed on level ground with a number of 4 × 8-foot sheets of 1/2-inch-thick plywood arranged in a semicircular arena. The plywood panels were positioned at a nominal distance of 12 feet from the basket center with one at 9 feet and another at only 6 feet. A wooden stand was placed on either side of the basket, one at 6 feet and the other at 12 feet, distances that might be typical of two men working near the bomb basket. The body armor, hand-held shields, and helmets with face shields were placed on these wooden stands. Fragments resulting from detonations which struck the shields, helmets, and witness panels were examined and evaluated.

It was expected that the shields and body armor would offer some additional protection from blast pressure. In order to verify and measure this characteristic, additional pressure gages were used. A gage was mounted behind the body armor at 6 feet and another in the open at the same distance for comparison purposes. Another pair of gages were similarly placed with the shield and armor 12 feet away. Hence, there were four pressure gages used for each fragmentation test in which the blast pressure was expected to be significant.

Still color photographs were taken before and after most test shots (about 150 throughout the testing procedure). Motion pictures at 200 frames per second were taken of most of the test shots involving fragmentation bombs.

2. TESTS CONDUCTED

A total of 18 test shots were performed using both open- and closed-bottom bomb baskets. Shots 1 through 9 were conducted for blast pressure data; Shots 10 through 17 were conducted as fragmentation tests. Finally, Shot 18 was an effort to determine if the bomb basket could be used for more than one detonation.

The blast pressure tests were carried out with 1-pound TNT charges. TNT was selected for this purpose because it is a widely recognized, standard explosive for which a great deal of technical information is readily available. When placed in the bomb basket, the TNT charge was suspended roughly 1 foot above the ground. To obtain a direct comparison of the basket's ability to directionally vent the explosive shock waves, bare charges (without the basket) were elevated 1 foot above the ground and detonated. Three preliminary tests (Shots 1 through 3) were scheduled to verify proper equipment operation and instrument calibration.

Shots 4 through 9 were conducted to acquire data for analyzing blast wave behavior. It was desired to have a set of data for the TNT detonation with and without the bomb basket. Since three tests were required to obtain 24 data points using only eight gages, the shots without baskets were made alternately with the shots using baskets so that the gage positions needed to be set or changed only three times. A diagram illustrating the pattern of data measurement points is provided in Figure 1, page 3.

The following is a list of range tests as scheduled:

SHOT NO.	DESCRIPTION
1	Instrument calibration test, 1 pound of TNT, no basket.
2	Same as Shot 1.
3	Same as Shot 1.
4	Blast test, 1 pound of TNT, no basket, instrumented for pressure data acquisition.

SHOT NO.	DESCRIPTION
5	Blast test, 1 pound of TNT, closed-bottom basket, instrumented for pressure data acquisition.
6	Same as Shot 4, pressure gages repositioned.
7	Same as Shot 5.
8	Same as Shot 4, pressure gages repositioned.
9	Same as Shot 5.
10	Fragmentation test, black powder pipe bomb, closed-bottom basket, motion picture coverage.
11	Same as Shot 10 using smokeless powder pipe bomb.
12	Same as Shot 10 using dynamite-filled pipe bomb, pressure gages positioned with body armor.
13	Same as Shot 10 using composition C-4 pipe bomb and open-bottom bomb basket.
14	Fragmentation test, M26 fragmentation hand grenade, ceramic-lined basket, motion picture coverage, not instrumented for pressure.
15	IED test, five sticks of 40% dynamite, closed-bottom basket, motion picture coverage and pressure instrumentation.
16	Same as Shot 15 except 10 sticks of dynamite and open-bottom basket.
17	Same as Shot 16 except 15 sticks of dynamite.
18	Basket endurance test, 10 consecutive charges consisting of two sticks of dynamite each, open-bottom basket.

With two exceptions, all of the scheduled tests were conducted.

First, Shot 3 yielded good data; all instrumentation operated properly and the data was recorded and used for the desired analytical purposes. Shot 4 was cancelled in lieu of Shot 3. Second, an equipment malfunction was experienced with Shot 9, resulting in incomplete data. Consequently, it was reconducted and designated Shot 9A.

Shots 1 through 9 used 1 pound of TNT. Most shots were made using two 1/2-pound blocks taped together. In a few instances a single 1-pound block of TNT was used. In all cases priming was accomplished by means of a single, military-type, Corps of Engineers special electric blasting cap. In Shots 10 and 11 pipe bombs containing black and smokeless powders, respectively, were used. For these shots, initiation was accomplished by means of Type S-75 electric squibs placed in the center of the powder charge at the time the pipe bombs were loaded and assembled. Shots 12 and 13 were made with pipe bombs containing high explosive fillers. These were primed with Corps of Engineers special electric blasting caps inserted through a hole drilled in one of the end caps. Shot 14 was made with a fragmentation hand grenade. In this instance, the grenade fuze was removed and an electric blasting cap was inserted into the detonator well. Shots 15, 16, 17, and 18 were all made using commercial dynamite and were single primed with electric blasting caps. Appendix A gives specific details of each explosive charge and device.

3. RESULTS

A. Blast Test Results

A considerable amount of data is available pertaining to the characteristics of TNT explosions. Velocity of the shock wave, peak dynamic overpressure, pressure impulse, and decay parameters as a function of distance, have been extensively tabulated. Formulas for scaling relative weights and distances can be used to equate any TNT explosion to the tabulated data. In order to obtain the blast pressure values for the free air charges, 1-pound TNT charges without the bomb baskets were detonated at a height of 1 foot above the ground. Pressure gages placed on the same horizontal plane as the charges gave a double peak pulse. The second peak, which was clearly distinguishable on the oscilloscope displays, was a shock wave due to ground reflection. In some cases, the reflected wave was of greater magnitude than the initial wave. For purposes of evaluating the hazard potential resulting from blast overpressures, the higher of the two peaks was measured and recorded. In cases where casualties may be caused by blast pressure, it is incidental whether an injury is caused by an initial shock wave or a reflected one. The overpressures observed at the 24 measurement points around the free air reference charges are given in Figure 2, page 7.

Only the closed-bottom bomb basket was used for blast redirection tests (Shots 5, 7, and 9). It was considered that the open-bottom basket, when sitting on the ground, would have blast redirection characteristics substantially the same as those of the closed-bottom basket. There would be a noticeably different situation if a detonation occurred in an open-bottom basket that was suspended above the ground. Because the BHS's manufacturer does not recommend lifting or carrying either type of basket above the ground, the elevated position characteristics were not investigated.

The pressure gage positioning arrangement was selected in an attempt to determine the blast wave distortion pattern in the vicinity of the basket. An effort was made to construct an isobaric chart indicating the shape of the lines of constant pressure radiating from the charge. Six gages were placed in the same horizontal plane as the charge (1 foot above the ground) at distances of 3 to 20 feet. Similar positions were monitored in horizontal planes at 3 and 6 feet above the charge. A few positions were monitored in a plane 9 feet above the charge. Also monitored were points in a vertical line directly above the charge at heights of 3, 6, and 9 feet. The array of gages varied in absolute distance from as close as 3 feet to an extreme of 20.9 feet. The measured overpressures at the 24 points varied from a high near the blast of about 250 psig to a low at the extreme distances of about 2 psig. Hence, overpressures varying over two orders of magnitude were observed. The type of gage used for the tests is expected to be accurate within ± 2 percent; this leads to uncertainties due to experimental error. Additional errors may have resulted from charge orientation and technique of priming.

The shape of the bomb basket indicates that blast waves would be directed upward with greater intensity than from a charge in free air. The intensity of the shock wave radiating outward horizontally should be noticeably reduced. The basket vents the blast in a manner analogous to a parabolic reflector. The side areas are of primary interest because personnel would normally be standing or working at some distance out to the side of the basket. The region of space directly above the basket is generally considered to be a safe direction for blast venting. This area does, in fact, receive shock waves of higher than normal intensity. However, this situation could present difficulties when the basket is used within the confines of a building. Shock waves directed upward would be reflected from ceilings or overhead structures. It is conceivable that this could present a more severe case than would occur without the basket.

Readings from the pressure gages during the blast tests show a marked increase in explosive shock overpressure directly above the basket. At 3 feet above the charge the indicated pressure was about 2 1/2 times (249 vs. 109 psig) the pressure measured above a similar charge in free air. Corresponding results were noted at heights of 6 (52 vs. 27 psig) and 9 (21 vs. 8.6 psig) feet.

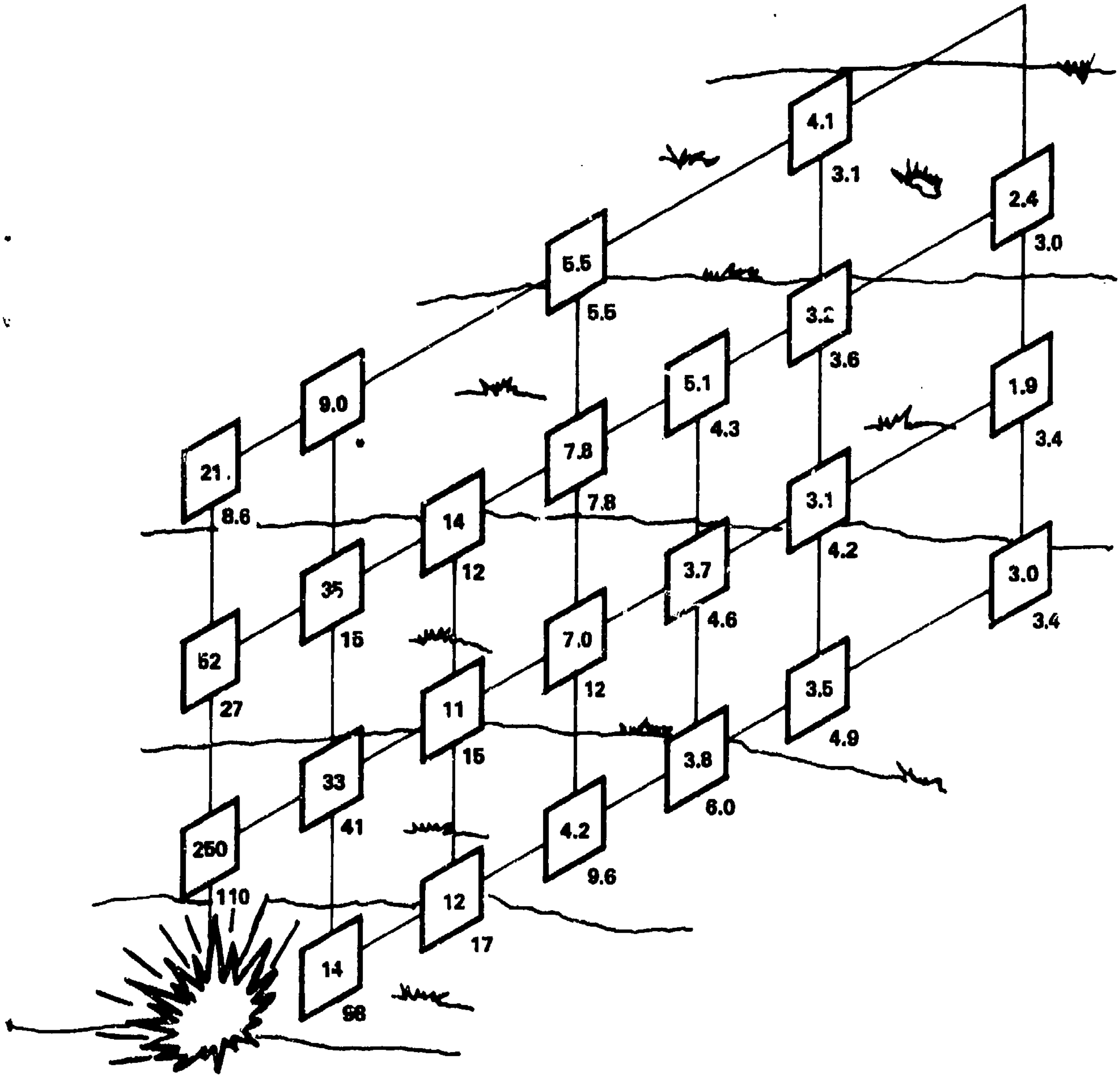


Figure 2. Peak dynamic overpressures (psig) for 1-pound TNT charges as measured in test Shots 4 through 9. Values represent the in-basket pressures (boxed figures) and the free air pressures.

*No data—gage malfunction.

Reductions in blast pressure were noted out to the side of the basket along the same horizontal plane as the charge. The side pressure reduction was most dramatic at points closest to the basket. At 3 feet outside the basket, a reduction of nearly 86 percent (from 98 to 14 psig) was noted. At 9 feet, the reduction was 56 percent (from 9.6 to 4.2 psig) and at 15 feet, only 28 percent (from 4.9 to 3.5 psig). At further distances, the side pressures were reduced by smaller amounts. This effect of diminishing attenuation is an expected result of wave diffraction characteristics. It is estimated that at distances greater than 50 feet the basket would have no measurable attenuation capability for 1-pound TNT charges. The horizontal plane 3 feet above the charge (4 feet above the ground) was of greater significance because it is roughly at chest level for personnel in the area of the basket. Pressures along this plane were also reduced by in-basket detonations, but reduction percentages were smaller. At the higher planes the reductions began further away from the basket and were even less noticeable. Actual pressure data for the free air and in-basket shots are presented in Figure 2, page 7. A rough sketch of the family of constant pressure curves is given in Figure 3, page 9. Based on the observed pressure data, it is considered that a distance of 20 feet or more should be maintained by personnel to avoid possible injury. Appendix B gives information regarding the casualty-producing potential of explosive shocks in air.

Shots 5, 7, and 9 were conducted with 1-pound TNT charges. An examination of the basket was made after each shot. In none of these cases did the basket appear to be significantly damaged. In some cases, the basket jumped upward a few feet due to sidewall and bottom flexing and came to rest within 10 feet of its original location. The heavy rubber rim, used to hold the nylon netting, was blown off in every case. This rubber rim, generally in one or two pieces, was found at distances greater than 100 feet from the basket in some cases. It is obvious that even with explosive charges producing few or no fragments, the basket's rubber rim becomes a missile capable of causing injury. Dramatic evidence of this became apparent in Shot 16 when a piece of the rubber rim was propelled with sufficient velocity to embed itself in a plywood witness panel (see Figure C-44 in Appendix C).

The TNT charges used for blast pressure measurement were standard, military demolition blocks having thin metal end caps. When the charges were detonated, these metal end caps struck the inside walls of the basket. At opposite points coincident with the linear axis of the block charge, partial failure of the basket wall material was apparent. The first and sometimes the second fiber glass laminations, both inside and outside the basket, showed damage similar to spalling. In no case (Shots 5, 7, and 9) were there any complete wall penetrations. In Shot 9A (a rerun of Shot 9) the metal end caps were removed from the 1-pound TNT block with the result that the surface damage described above did not occur.

B. Fragmentation Test Results

Shot 10 was conducted using a pipe bomb containing 2/3 pound of commercial black powder (grade FFFg). Upon initiation the pipe ruptured in several large pieces, indicating a low velocity detonation. The end caps failed by having a circular disk blown out of each end. Damage to the bomb basket was hardly noticeable. Although the nylon netting and rubber rim were blown clear of the basket, no pipe fragments penetrated the basket walls. There was no evidence of fiber glass delamination.

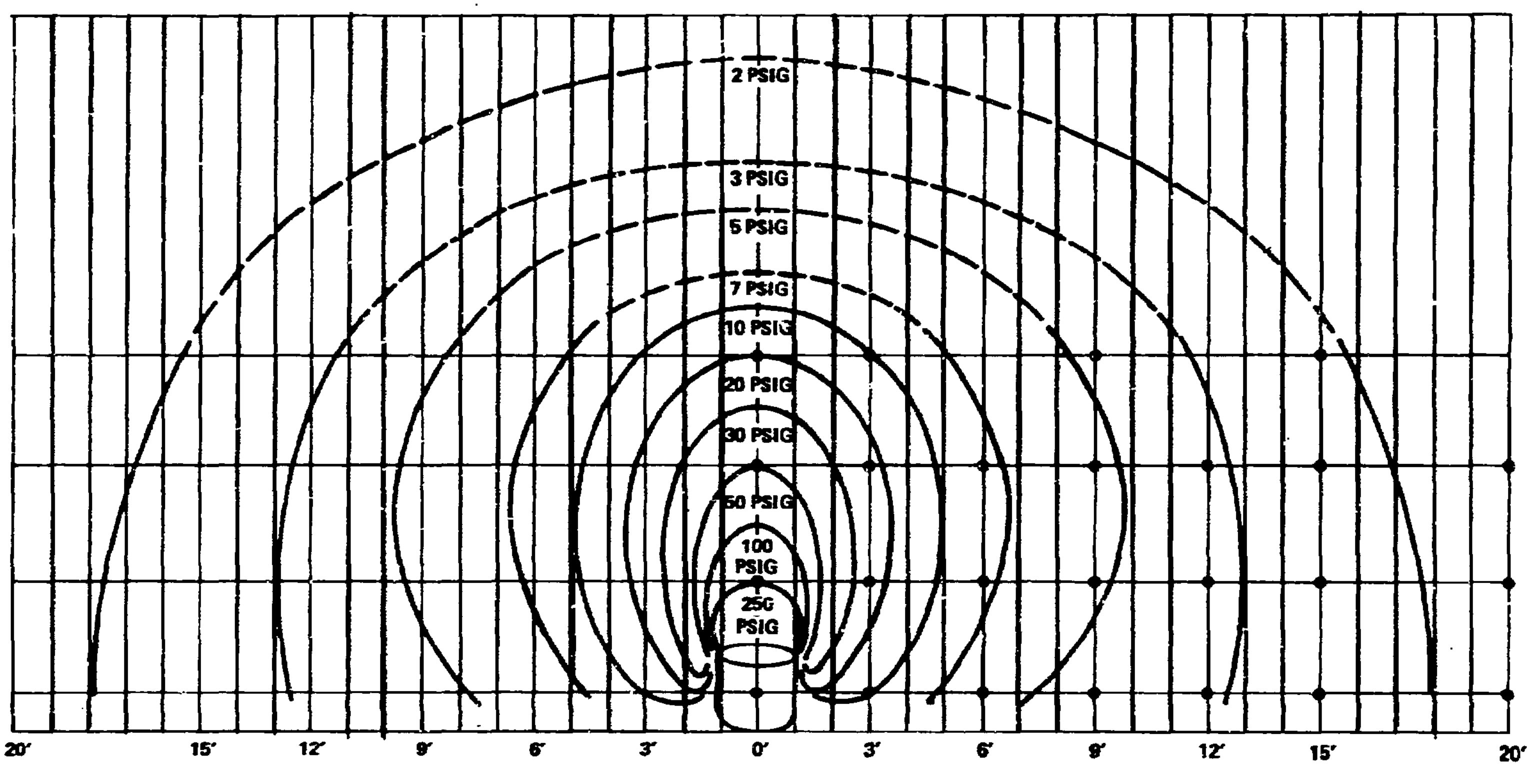


Figure 3. Approximation of the family of constant pressure curves (values in psig) based on data from test Shots 5, 7, and 9 performed in a closed-bottom bomb basket. At distances greater than 10 feet, the shock waves are essentially spherical.

Shot 11 was conducted with a pipe bomb containing about 1/3 pound of double base, smokeless powder (Hercules Bullseye). The explosion was noticeably more energetic than in Shot 10. The pipe end caps fragmented in a manner similar to the preceding shot, however, the pipe body ruptured into a larger number of smaller pieces having sufficient velocity to penetrate the basket walls. At least six total penetrations of the wall were apparent. No fragment impacts could be found on the plywood witness panels or personnel shields. One piece of an end cap was noted as having struck the wooden base on the stand supporting the body armor and shield. Results indicate that the basket provides a reasonable degree of protection from this type of explosive device.

Shot 12 was conducted using a pipe bomb containing about one and one third sticks of commercial dynamite (1 1/4 × 8-inch sticks of DuPont Red Cross 40 percent). Detonation was violent and produced a large number of high-velocity metal fragments, many of which penetrated the basket walls. As a result of the orientation of the pipe bomb when placed in the netting, few fragments were directed toward the shields and body armor. However, it was noted that one hit caused a surface indentation on a personnel shield. The plywood witness panels showed a total of 15 hits, of which six were incomplete and nine were complete penetrations. Fragments striking the plywood first passed through the basket walls, however, the hits noted were considered capable of causing serious injury to unprotected personnel. The basket showed signs of severe damage.

Shot 13 was conducted with a pipe bomb containing 2/3 pound of military plastic explosive (composition C-4). Detonation produced a large number of very high velocity fragments. Fragments originating from the pipe body struck and penetrated the basket walls in sufficient numbers to actually cut the basket into two pieces. Several dozen hits were noted on the personnel shields, three or four of which penetrated completely, but were stopped by the body armor. Over 150 hits were counted on the plywood witness panels, about 50 of which were complete penetrations. The face shields on the personnel helmets each received one hit which passed through the plastic. It was apparent that the basket provides only minimal protection from this type of device.

Shot 14 was conducted with the smaller ceramic-lined basket which is intended specifically for fragmentation-type explosive devices. A military M26 fragmentation hand grenade containing 8 ounces of composition B as a bursting charge and a uniformly fragmenting body was detonated in the basket. Upon initiation, the ceramic lining was completely broken into small pieces which fell to the bottom of the basket. No fragments penetrated the fiber glass outer wall; horizontal containment appeared to be complete and highly efficient.

Shots 15, 16, and 17 were made with IED's containing five, 10, and 15 sticks respectively, of commercial dynamite (see Appendix A for a description of IED construction). The closed-bottom basket, in which Shot 15 was fired, appeared to provide a good degree of protection. Although the basket bounced and came to rest about 10 feet from its original position, it was found to be in relatively good condition, showing only minor signs of delamination. There were no wall penetrations resulting from the miscellaneous hardware in the IED. Shot 16 was fired in an open-bottom basket, and the basket was severely damaged. The basket remained loosely intact, indicating that 10 sticks is probably a charge size limit for this type of basket. Shot 17 was also fired in an open-bottom basket, however, the 15 stick charge caused dramatic overdestruction. The entire basket was fragmented into pieces of fiber glass, the largest of which measured about 1 foot in length. Pieces of the fiber glass wall were found several hundred feet from the point of detonation. All but one of the plywood witness panels were blown down. Several of them showed large holes where portions of the basket wall perforated the plywood. It was obvious that an IED of this size, which produces relatively few fragments by itself, exceeds the strength of the basket to a point where the basket material contributes a significant amount of fragmentation. Hence, the detonation of this type of IED in a bomb basket may present a somewhat greater fragmentation danger than when detonated by itself.

Shot 18 consisted of 10 consecutive detonations of two sticks of dynamite each. The first charge, as expected, destroyed the nylon netting and rubber rim. Subsequent charges were suspended in the center of the basket by means of paper masking tape. Little or no damage to the basket wall material resulted from the first few explosions, but by the fifth shot some fraying of the basket rim at the bottom became apparent. This slight delamination progressively worsened as the number of shots increased. By the 10th shot, the bottom of the basket showed a moderate amount of delamination, but most of the wall structure was substantially intact and sound. It is likely that several more explosions of this type could have been made before damage progressed to the point of rendering the basket useless.

4. ACCESSORY PROTECTION

Shots 10 through 17 were carried out in a semicircular fragmentation arena. The personnel helmets, body armor, and shields were positioned on wooden stands at distances of 6 and 12 feet from the basket. Pressure gages were placed at the same distances for Shots 12, 13, 15, 16, and 17. Readings from the gages placed behind the body armor indicate an average pressure reduction of about 70 percent (see Table I, below). It can be concluded that a significant amount of shock wave attenuation is offered by the personnel protective equipment. No measurements were made to indicate the blast attenuation capabilities of the helmets with respect to possible ear injury; the helmets appeared to be effective for fragment protection. The face shields, however, were easily penetrated. Throughout the series of tests, the same sets of armor with shields were used. Numerous metal fragment impacts were observed on the shields, but in no case did any material penetrate both the shield and body armor. In this respect, the equipment provides excellent protection from casualty-producing fragments. After numerous hits (see Figures C-27, C-28, and C-29 in Appendix C) the personnel equipment was sufficiently intact for further testing or use.

TABLE I

BLAST PRESSURES RECORDED FOR PIPE BOMB AND IED TESTS

Test shot no.	Type of charge	Pressure (psig)			
		6 Feet		12 Feet	
		Free air	Behind armor	Free air	Behind armor
10	Black powder pipe bomb[1]	—	—	—	—
11	Smokeless powder pipe bomb[1]	—	—	—	—
12	Dynamite pipe bomb	2.7	0.85	2.7	0.80
13	C-4 pipe bomb	5.7	1.6	3.3	1.1
14	Hand grenade[1]	—	—	—	—
15	5-stick IED	9.2	1.7	4.0	2.0
16	10-stick IED	12.3	2.8	6.5	2.8
17	15-stick IED	15.8	3.8	11.0	4.3

[1]Not measured.

CONCLUSIONS

The following conclusions regarding the Protective Devices Bomb Handling System have been made based on the results of the range tests.

1. Both bomb baskets, open- and closed-bottom type (when sitting on the ground), have the capability to directionally vent explosive shock waves in an upward direction. Shock waves radiating horizontally outward are substantially decreased in intensity at distances of 10 feet or less. However, at distances of 20 feet or more, the side line shock wave attenuation rapidly becomes minimal.

2. The explosive charge limit at which the basket will remain intact is estimated to be 3 to 4 pounds of commerical 40 percent dynamite (six to eight sticks) for the closed-bottom basket and 4 to 5 pounds (eight to ten sticks) for the open-bottom basket. This statement presumes a nonfragmenting explosive device. The charge size limitations for more energetic military explosives would be lower.

3. In cases where an explosive charge exceeds the basket capacity, the fiber glass material breaks into pieces creating an additional fragment hazard. Devices containing 7 pounds or more of high explosive may be more dangerous when detonated in a bomb basket as a result of the basket fragmentation.

4. The bomb basket material is capable of resisting or significantly retarding metal fragments of relatively low velocity as produced by devices containing low explosives such as black and smokeless powders. The basket is not capable of stopping high velocity metal fragments from devices containing high energy explosives.

5. The ceramic-lined basket provides excellent protection from grenade-sized fragmentation generating devices.

6. The heavy rubber rim provided on all types of baskets was blown off in every test case. It is felt that this rim is propelled with sufficient velocity to cause serious injury, and so adds to the missile hazard.

7. The basket is reusable for small size charges well below the explosive limit. Minor damage does not appear to significantly reduce the basket strength.

8. The personnel body armor and shields provide very good protection from high velocity fragments and a significant reduction in blast overpressure.

RECOMMENDATIONS

1. The decision for use of the BHS should be based upon an evaluation (or estimation) of the relative size of the device to be handled. Users should be aware that for large size explosive charges, use of the basket may result in a greater fragmentation effect.

2. The personnel body armor and shields should be used with the BHS at all times. It is recommended, however, that effective ear protection devices (such as ear plugs) be used to supplement the equipment.

3. When using the BHS, it is recommended that personnel approach no closer than 20 feet, except when absolutely necessary.

4. It is suggested that the heavy rubber rim be removed and the nylon netting be secured by other means if possible.

APPENDIX A

EXPLOSIVE ITEMS USED FOR TESTING

EXPLOSIVE ITEMS USED FOR TESTING

SHOT NO.	DESCRIPTION
1--9	Two 1/2-pound TNT demolition blocks were detonated for most tests. Shots 8, 9, and 9A were conducted with a single 1-pound block. All shots were single-primed with Corps of Engineers special electric blasting caps.
10	A pipe bomb made of standard schedule 40 steel pipe 1 1/2 × 8 inches was initiated for this test. The bomb contained 290 grams of commercial grade FFFg black powder and was initiated by a Type S-75 electric squib located in the center of the powder charge.
11	A pipe bomb similar to the one in Shot 10 was used for this test. The one difference was that this bomb contained 176 grams of Hercules Bullseye double base smokeless powder.
12	A pipe bomb similar to the one described above was loaded with 320 grams (1 1/3 sticks) of DuPont Red Cross 40 percent dynamite and single-primed with a Corps of Engineers special electric blasting cap. The detonating velocity was 10,200 feet per second.
13	A pipe bomb similar to the previous ones was loaded with 300 grams of composition C-4 military plastic explosive and primed as in Shot 12 for this test. The detonating velocity was 26,000 feet per second.
14	For this test an M26 fragmentation hand grenade containing 8 ounces of composition B was used. The grenade fuze was replaced with a Corps of Engineers special electric blasting cap.
15	For this test an IED was constructed from a typical 3-inch-wide attache case, a 6-volt dry cell battery, a wind-up alarm clock, several feet of wire, and five sticks of Red Cross 40 percent dynamite. This device was primed with a Corps of Engineers special electric blasting cap.
16	For this test an IED similar to the one used in Shot 15, except that it contained 10 sticks of dynamite, was used.
17	For this test an IED similar to the one used in Shot 15, except that it contained 15 sticks of dynamite, was used.
18	Ten charges made of two sticks of Red Cross 40 percent dynamite taped together and primed with a Corps of Engineers special electric blasting cap were consecutively detonated in one bomb basket for this test.

APPENDIX B

BLAST PRESSURE CASUALTIES

The peak dynamic blast pressure varies inversely with the distance from the point of detonation. The duration of the pressure pulse, however, varies directly with distance. For 1-pound TNT charges the pulse duration is about 0.001 seconds at 5.5 feet, 0.002 seconds at 15 feet, and 0.003 seconds at 50 feet. Explosive charges of greater than 1 pound in weight produce pressure pulses of longer duration.

To appreciate the hazard presented by explosive shocks as measured in this report, the following information[1] reflects the casualty potential for a 70-kg man where the long axis of the body is perpendicular to the direction of wave propagation. It should be noted that in cases where wave-reflecting objects, such as walls, are nearby the danger potential is considerably higher.

For 1.0 millisecond pressure pulses:

0–20 psi	Injury not likely
20–50 psi	Ear damage region
50–130 psi	Lung damage region
130–250 psi	Death possible
Above 250 psi	Death certain

For 2.0 millisecond pressure pulses:

0–12 psi	Injury not likely
12–32 psi	Ear damage region
32–80 psi	Lung damage region
80–160 psi	Death possible
Above 160 psi	Death certain

For 3.0 millisecond pressure pulses:

0–5 psi	Injury not likely
5–25 psi	Ear damage region
25–60 psi	Lung damage region
60–120 psi	Death possible
Above 120 psi	Death certain

[1] Estimate of Man's Tolerance to Direct Effects of Air Blast, by Bowen, Fletcher, and Richmond. DASA-2113, October 1968.

APPENDIX C

TEST CONFIGURATIONS AND RESULTS

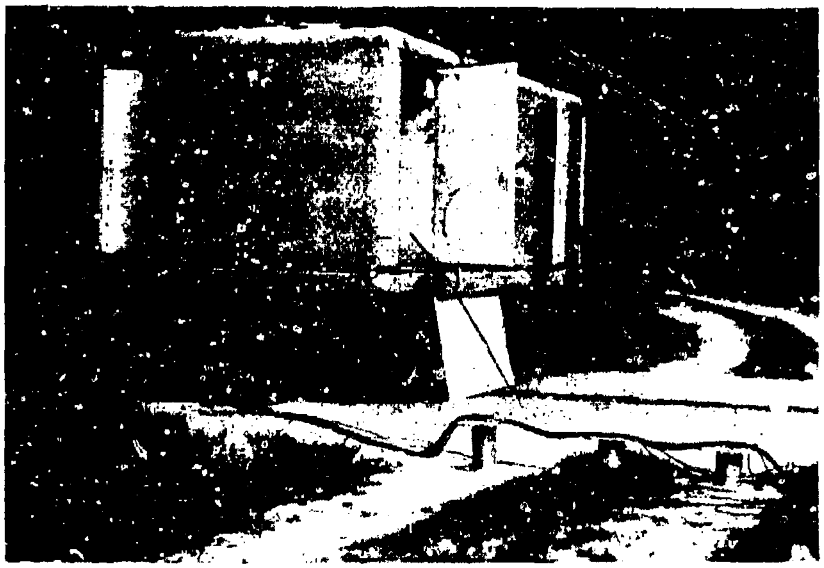


Figure C-1. A mobile trailer housed instruments used to measure blast pressure.

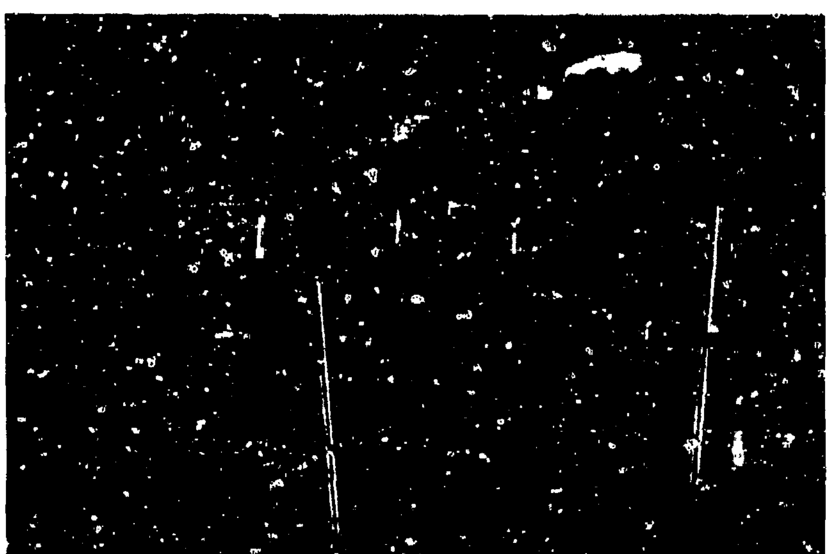


Figure C-2. Dual trace oscilloscopes with Polaroid cameras were used inside the equipment trailer for recording blast pressure.

Figure C-3. Blast pressure gages were secured to wooden stands at selected positions for Shots 1 through 9. Cables were run to the equipment trailer several hundred feet away.

Figure C-4. Piezoelectric "side-on" type pressure transducers were used for the tests. The gage closest to the charge was a special triggering gage.

Figure C-5. A gage placed directly over the charge required a modified stand.

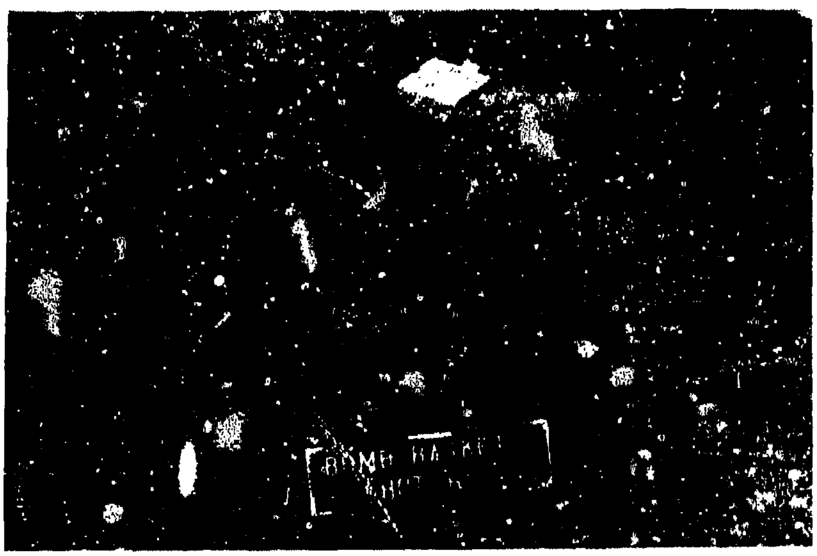


Figure C-6. TNT charges were elevated 1 foot above the ground and detonated in the open air for direct comparison with charges detonated in the bomb baskets.

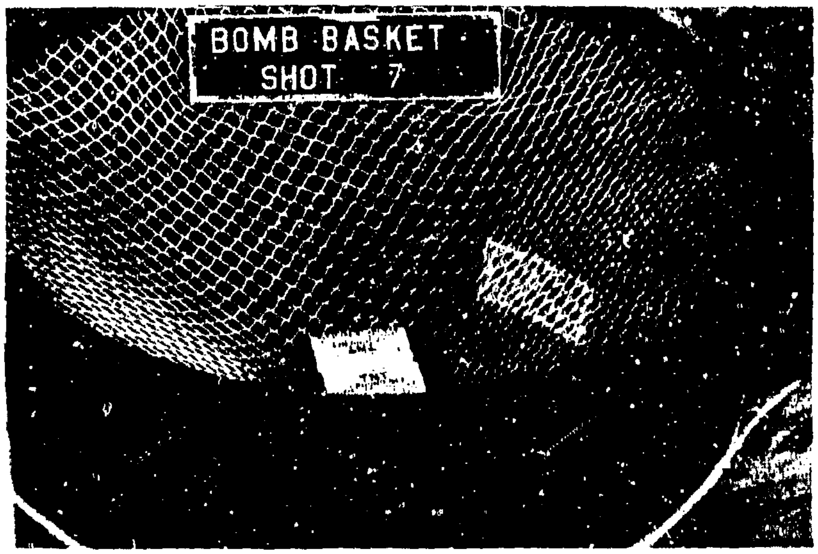


Figure C-7. Half-pound TNT blocks were used in pairs for 1-pound reference charges for most shots.

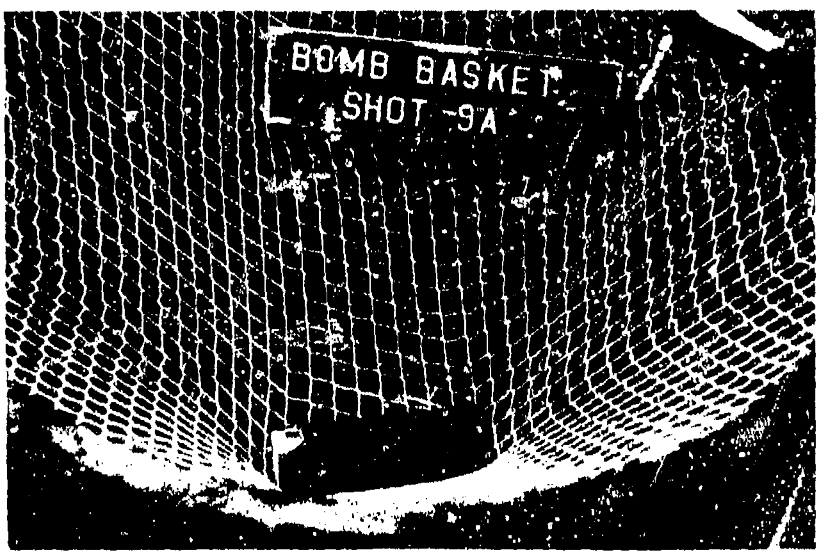


Figure C-8. Shot 9A was conducted with a single 1 pound TNT block. Basket wall damage was less than usual because the metal end caps were removed. Note the blast pressure triggering gage over the basket rim (upper right).

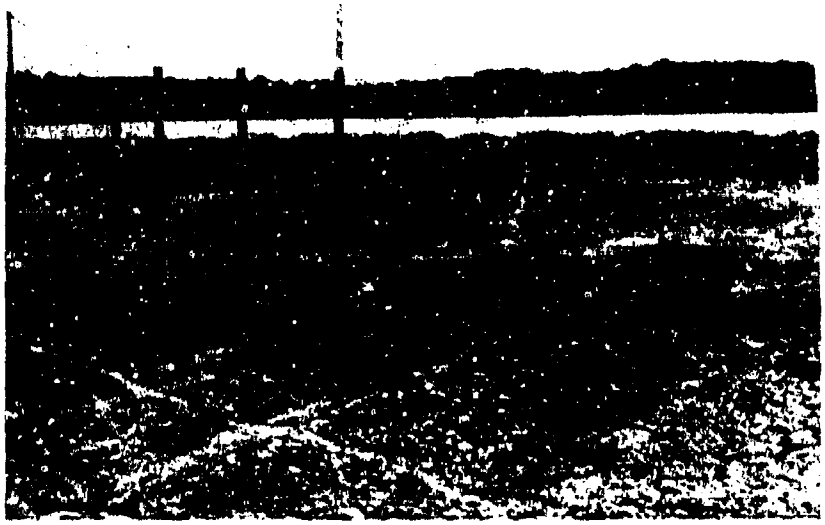


Figure C-9. The basket had a tendency to bounce when detonation occurred and came to rest some 15 feet from its original position.

Figure C-10. Damage to the closed-bottom basket from 1 pound of TNT was minimal. Some partial delamination of the wall material, caused by charge and caps, was apparent. Here, as in all shots throughout the series, the rubber basket rim was blown off and found over a hundred feet away. Note the charred remains of the nylon netting.

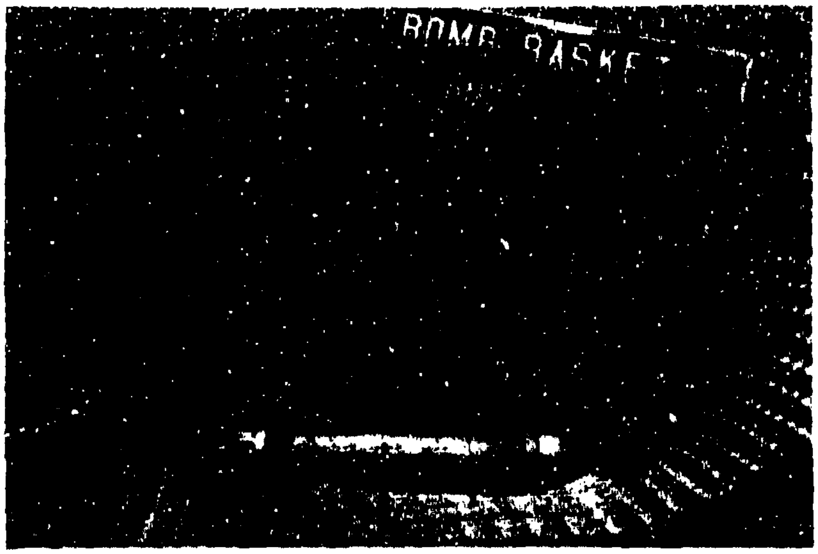


Figure C-11. A steel pipe bomb (1 1/2 x 8 inches) with end caps was used for Shots 10, 11, 12, and 13.

Figure C-12. Results from black powder-filled pipe bomb. Very little damage was done to the basket and no fragments penetrated the walls. Note the rubber rim in the background.

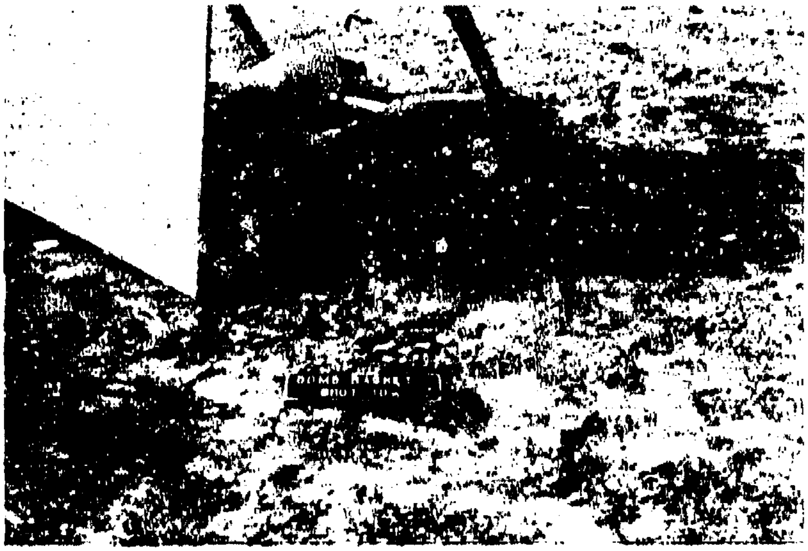


Figure C-13. A large portion of the end cap from the black powder pipe bomb was found a few feet from the basket. Explosive devices of this type typically produce large, low velocity fragments.

Figure C-14. When testing fragmenting explosive devices, personnel helmets, body armor, and shields were placed on stands at distances of 6 and 12 feet from the basket.

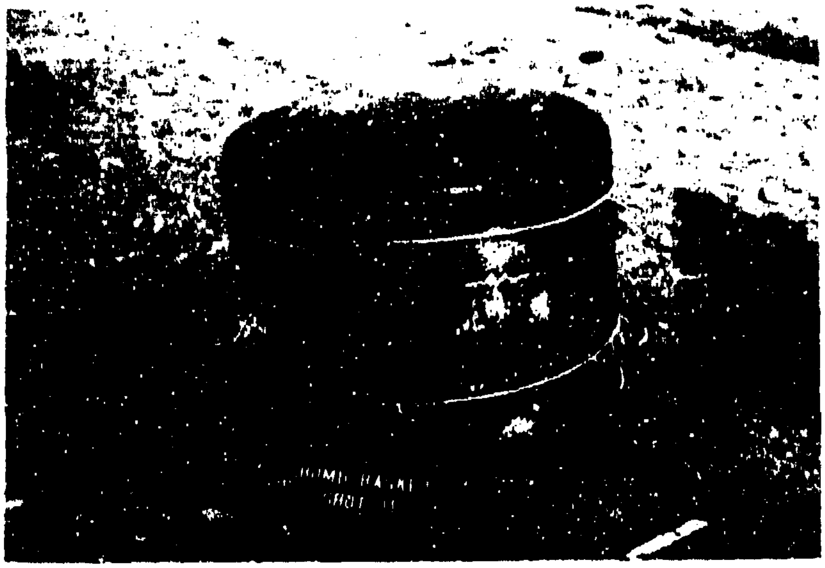


Figure C-15. The smokeless powder pipe bomb overturned the basket, and pipe end caps and several pieces of body section penetrated the basket walls.

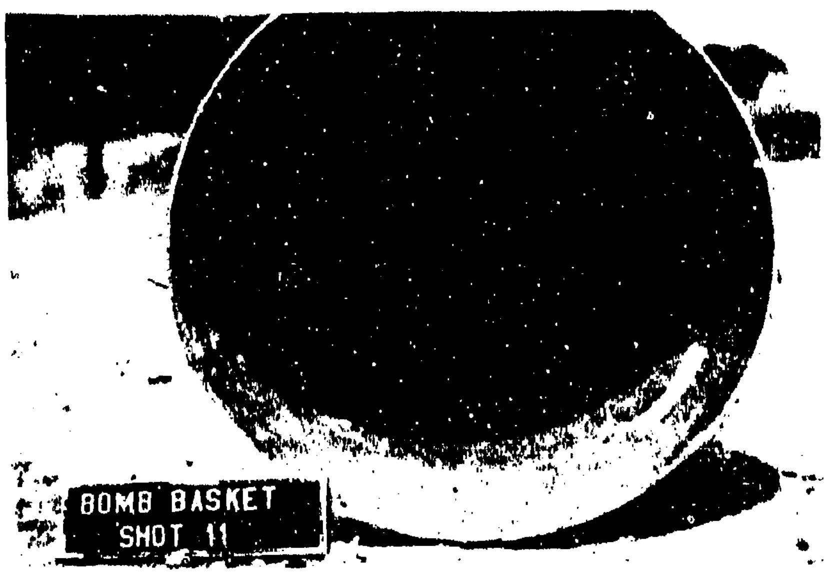


Figure C-16. A view of the inside of the basket shows fragment damage from the smokeless powder pipe bomb.

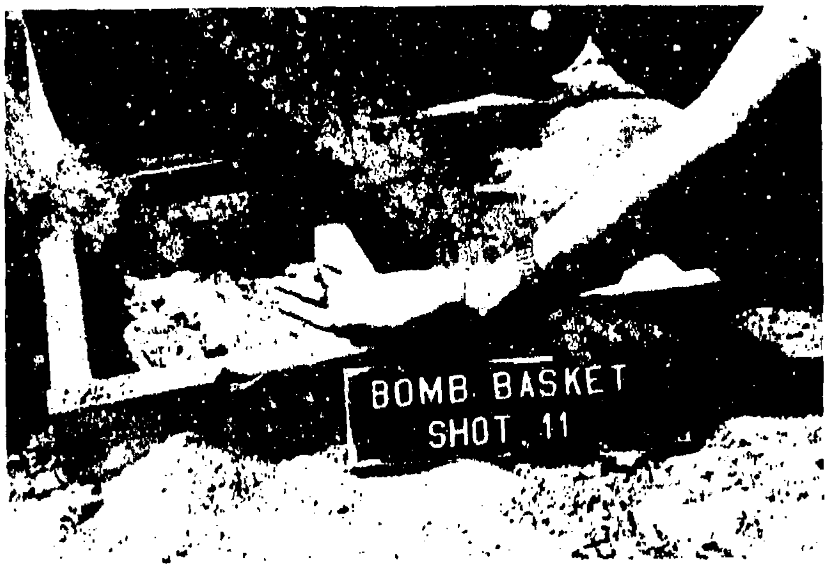


Figure C-17. A portion of the metal end cap perforated the basket wall with sufficient velocity remaining to damage a sandbag and the wooden stand.

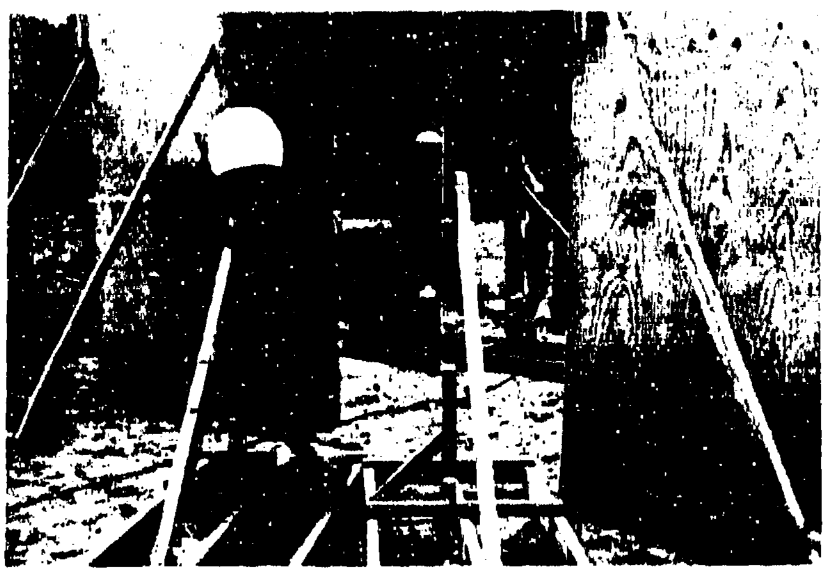


Figure C-18. A dynamite-filled pipe bomb was used for Shot 12. Pressure gages were placed behind and near body armor at 6 and 12 feet.

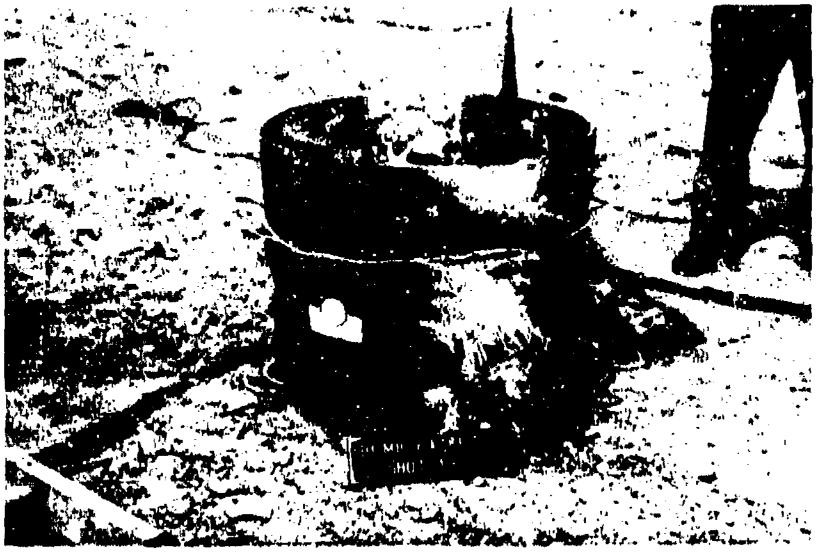


Figure C-19. Extensive damage resulted from a pipe bomb filled with 40 percent commercial dynamite.

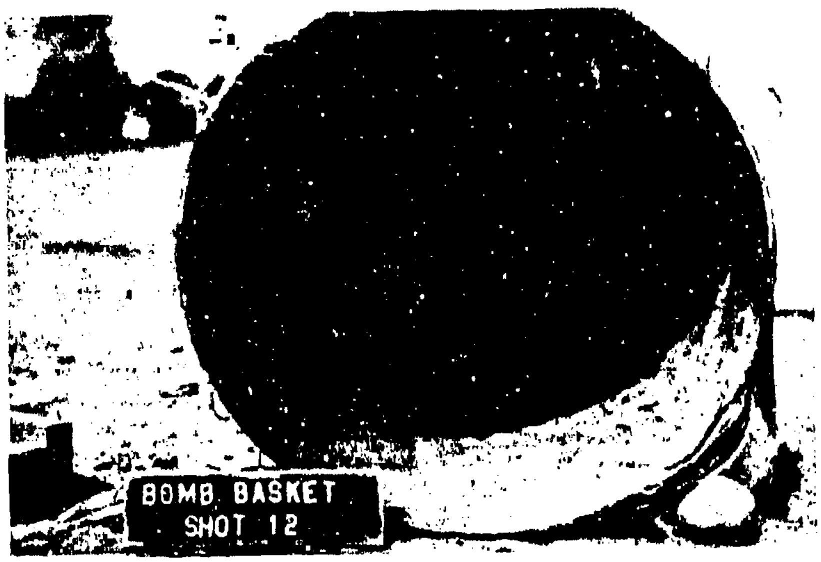


Figure C-20. An inside view of the basket after detonation of the dynamite pipe bomb shows hundreds of metal fragments perforated the walls.

Figure C-21. A part of the pipe end cap was embedded in the plywood witness plate after passing through the basket wall. Numerous small fragments perforated the plywood.

Figure C-22. An open-bottom basket was used in Shot 13 for the pipe bomb containing composition C-4 plastic explosive.

Figure C-23. The results from the detonation of the composition C-4 pipe bomb.

Figure C-24. The basket was cut in half from the multiple perforations of small metal fragments from the pipe body.

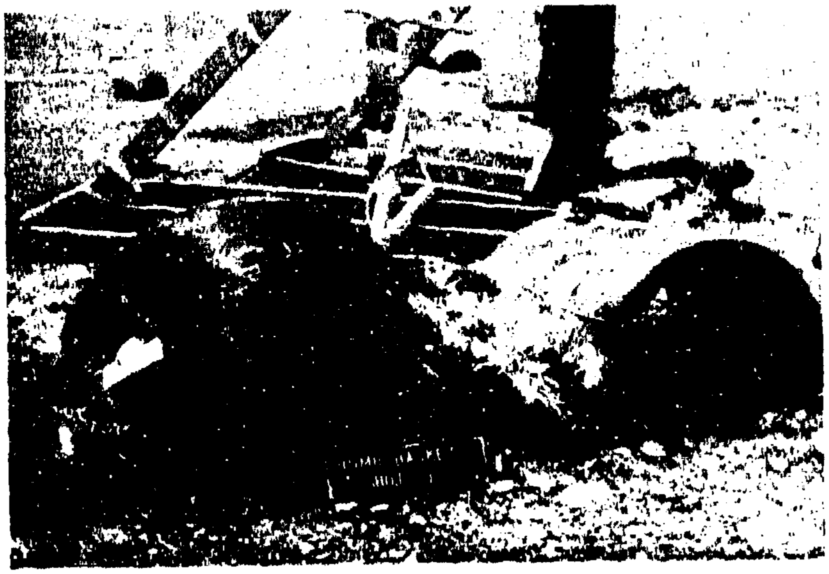


Figure C-25. The exterior of the basket shows the exit holes made by the end caps. The wall condition indicates relatively little blast pressure damage, but extensive destruction from high velocity fragments.

Figure C-26. The personnel shield 6 feet from the basket sustained numerous fragment impacts, five of which penetrated completely.

Figure C-27. Body armor successfully stopped metal fragments which passed through the shield. Note the perforation of the face protector.

Figure C-28. A side by side comparison of personnel shields from 12- and 6-foot distances shows that the fragmentation hazard decreases with distance.

Figure C-29. A view of the backs of the shields shows that no fragments penetrated the shield at 12 feet, while five fragments penetrated the shield at 6 feet.

Figure C-30. A witness plate 6 feet from the basket reflects the severe fragmentation hazard.

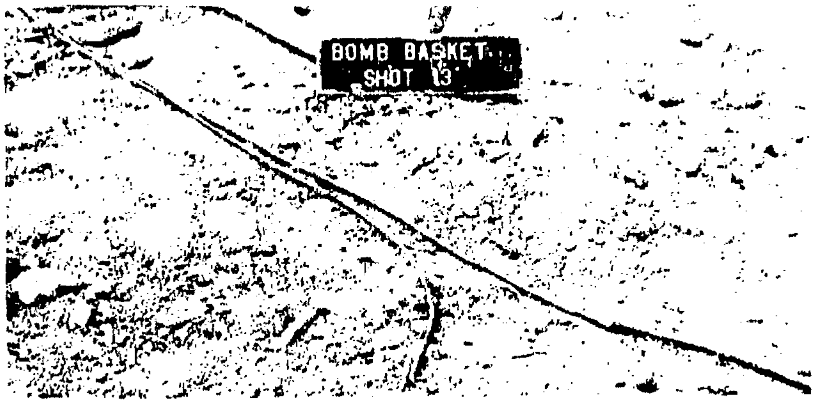


Figure C-31. A single metal fragment from the composition C-4 pipe bomb cut two pressure gage cables.

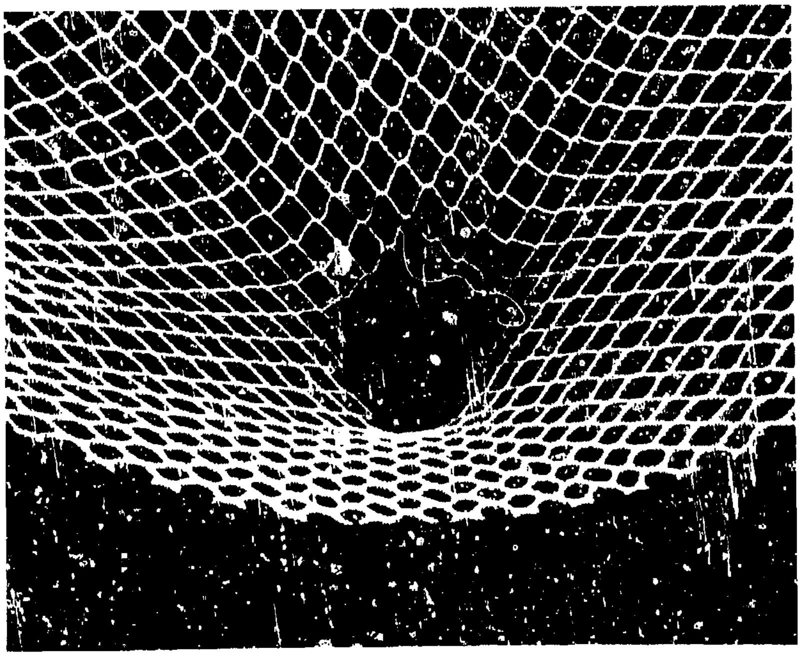


Figure C-32. An M26 fragmentation hand grenade was placed in a ceramic-lined basket for Shot 14.

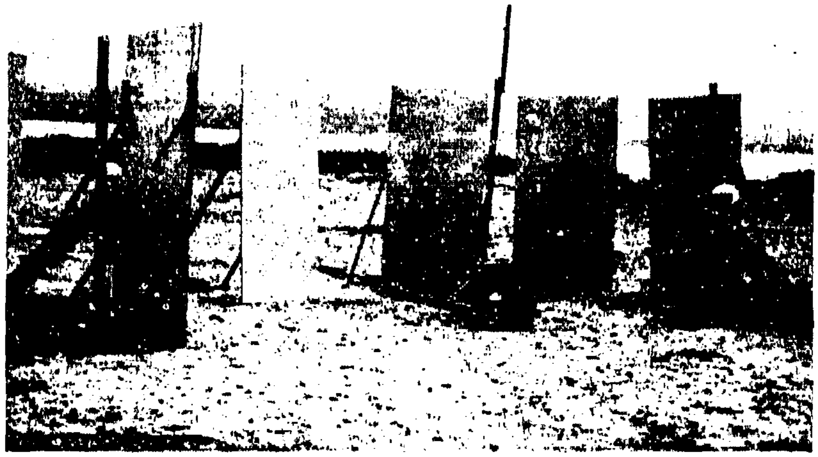


Figure C-33. The smaller ceramic-lined basket was placed on sandbags for a slight elevation.

Figure C-34. The ceramic lining was completely fractured, as intended, by the grenade fragments. No fragments penetrated the outer fiber glass wall, which remained intact.

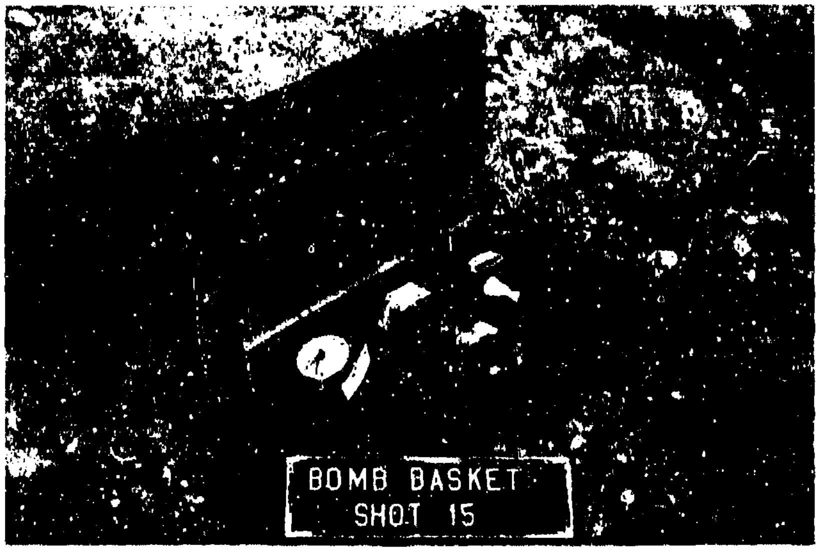


Figure C-35. An improvised explosive device (IED) was constructed using an attache case, a 6-volt dry cell battery, a wind-up alarm clock, several feet of wire, and commercial dynamite. Although primarily a blast device, incidental fragmentation results from the case hardware, battery, and clock.

Figure C-36. The attache case was placed inside the netting in a closed-bottom basket for Shot 15.

Figure C-37. The basket ca... to rest in the position shown after the detonation of the 5-stick IED.

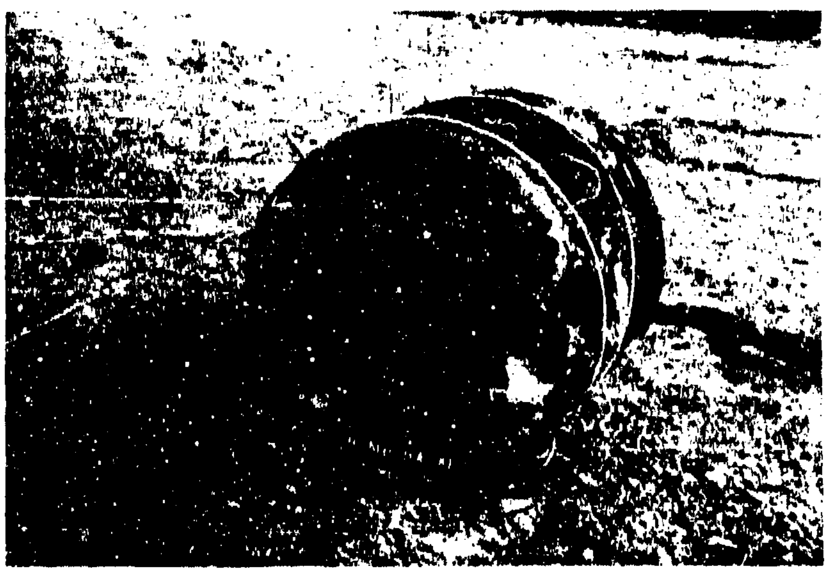


Figure C-38. The bottom of the basket after the detonation of the 5-stick IED shows minor delamination.

Figure C-39. The inside of the basket contained the remains of the attache case. The walls remained mechanically sound.

Figure C-40. The face protector from 6 feet shows a splattering of carbon material from the dry cell battery. The perforation was caused by Shot 13.

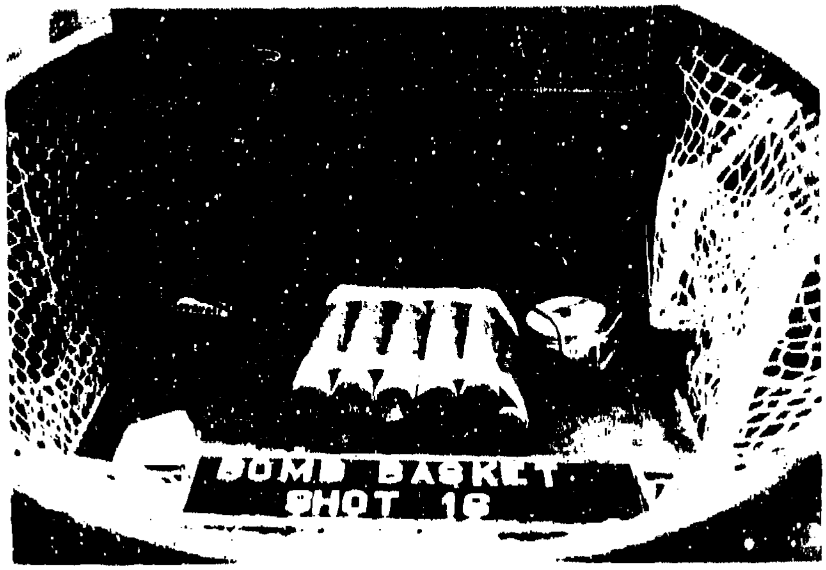


Figure C-41. A 10-stick IED was placed in an open-bottom basket for Shot 16.

Figure C-42. A view from the top of the basket after the detonation of the 10-stick IED shows little fragment damage.

Figure C-43. A view from the bottom of the basket after the detonation of the 10-stick IED shows nearly complete delamination of the walls although the basket is still loosely intact.

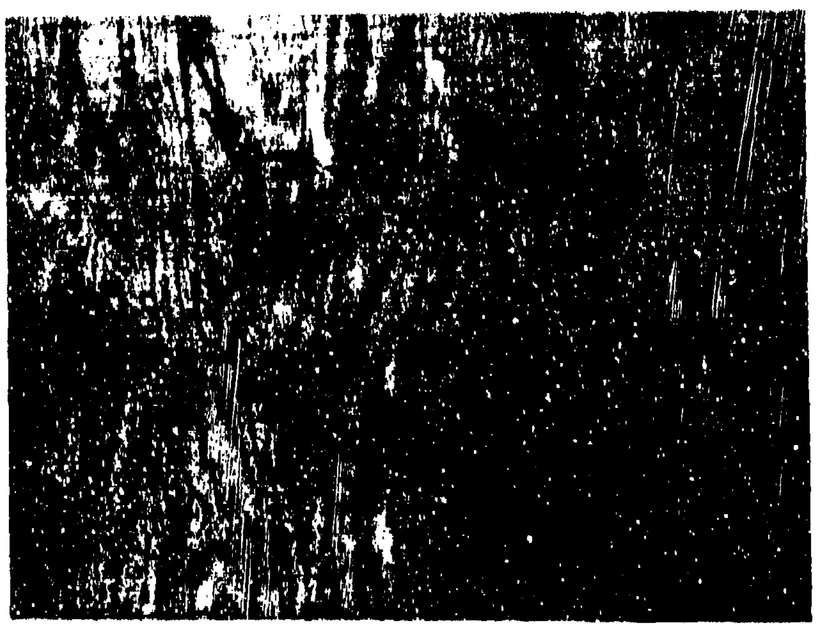


Figure C-44. A portion of the rubber basket rim was found embedded in a plywood panel. This extraneous missile, not part of the IED, was considered to have sufficient velocity to cause serious injury to personnel.

Figure C-45. Metal components from the alarm clock presented a fragmentation hazard.

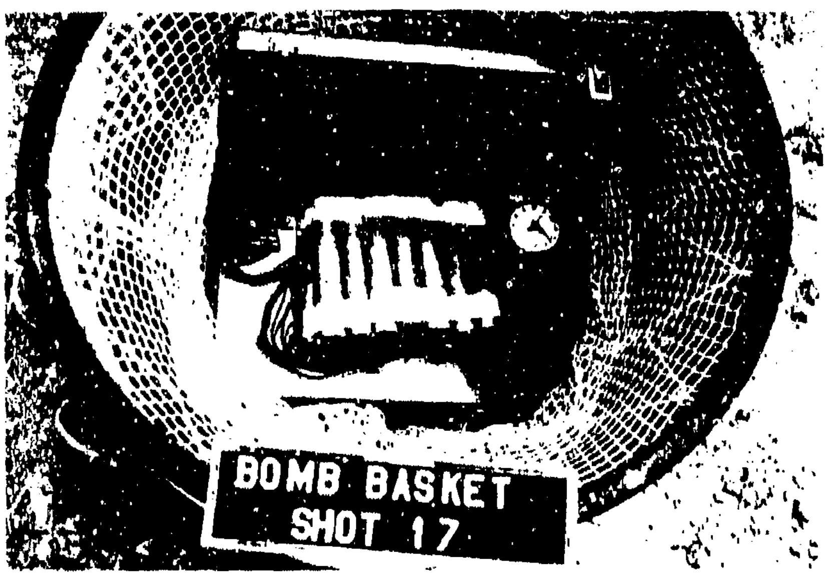
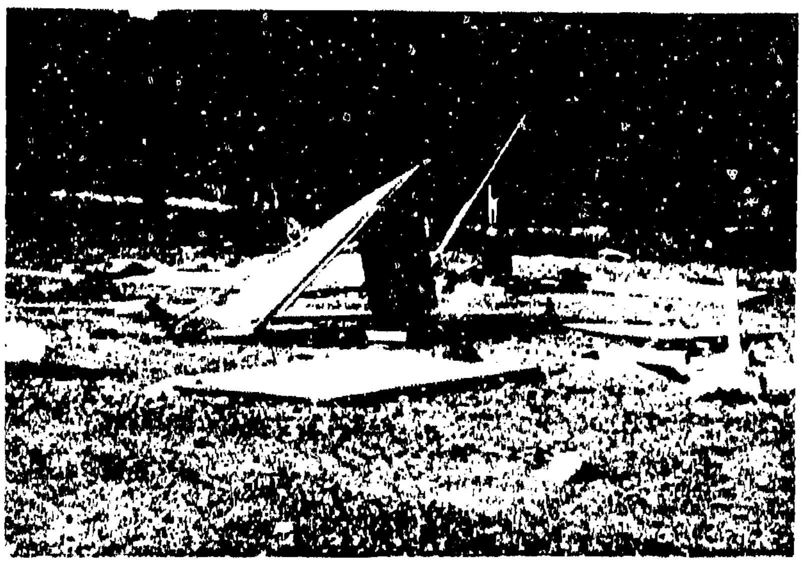


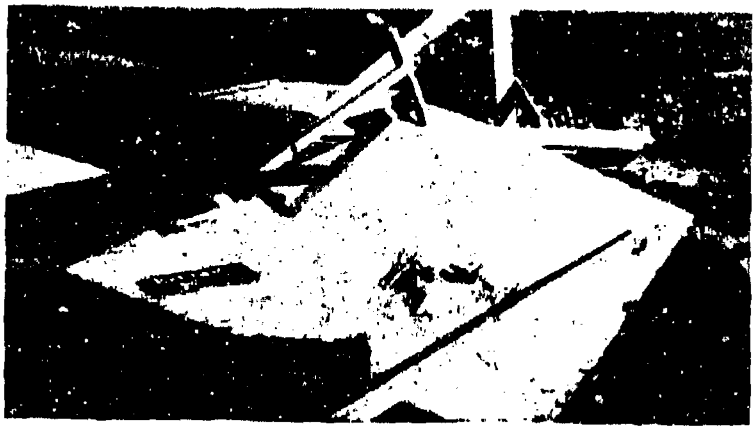
Figure C-46. A 15-stick IED was prepared for Shot 17.

VIEW A

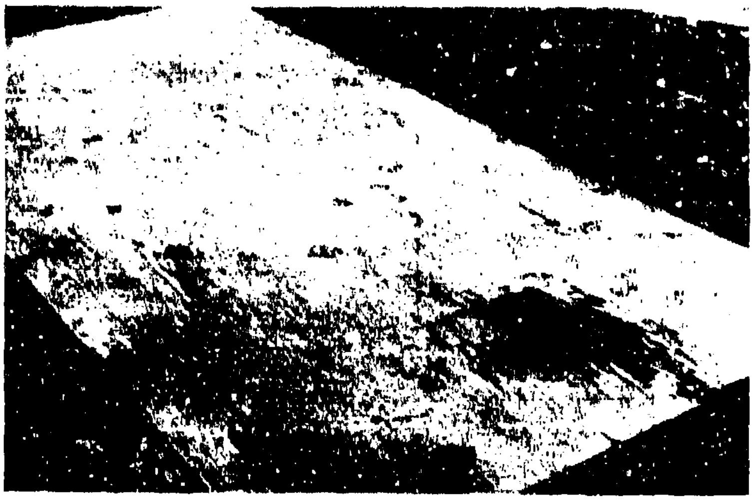


VIEW B

Figure C-47. An overall view of the range area after the detonation of the 15-stick IED shows only one plywood panel remained standing. The basket was completely destroyed, and pieces of fiber glass were found scattered hundreds of feet from the point of detonation.



VIEW A



VIEW B

VIEW C

Figure C-48. These plywood panels show extensive damage resulting from the basket material. When used with large IED's the basket contributes to the fragmentation hazard at short ranges.

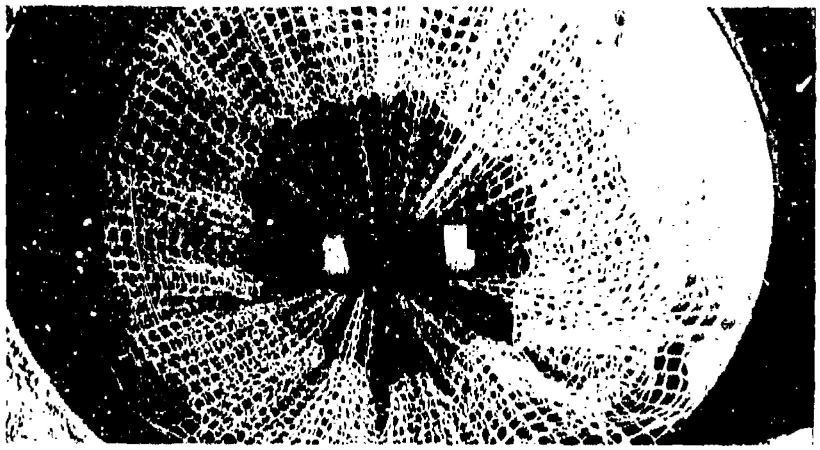


Figure C-49. Shot 18 was conducted with 2-stick charges of 40 percent dynamite in an open-bottom basket.

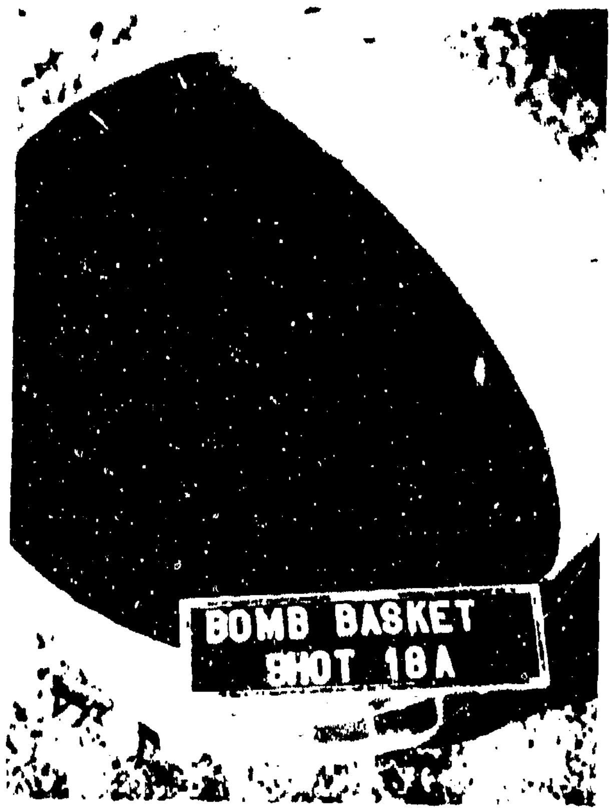


Figure C-50. After shooting the first 2-stick charge, the basket showed no structural damage, however, the netting and rubber rim were blown away.

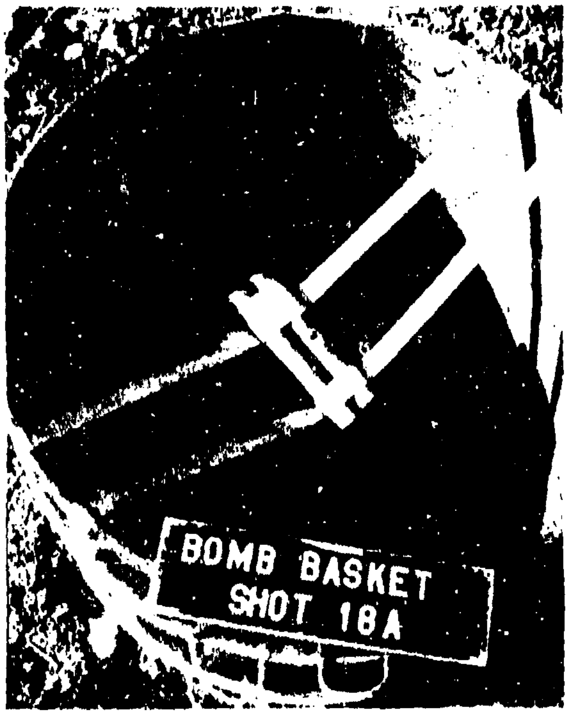


Figure C-51. Subsequent charges were placed in the basket by suspending them with paper masking tape.

Figure C-52. After seven detonations, some damage to the bottom section of basket was apparent.

Figure C-53. A view from the top of the basket shows the walls are in good condition even after 10 detonations.

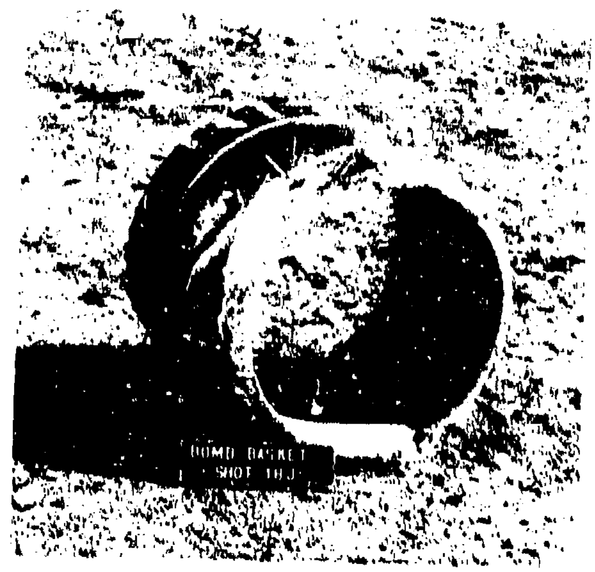


Figure C-54. A view of the outside of the basket after 10 detonations of 2-stick dynamite charges reveals damage. The bottom portion shows signs of material failure, but it is believed that many more shots would be required to totally destroy the basket.

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13. ABSTRACT

A series of tests were conducted with the Protective Devices Corporation's Bomb Handling System. TNT reference charges were detonated in the bomb baskets with pressure gages positioned in the area to determine blast pressure attenuation characteristics. Fragmentation-generating devices were detonated in the baskets to determine the degree of protection to personnel offered by the bomb baskets, shields, and body armor. On the basis of the test information conclusions regarding the bomb handling system's capabilities and limitations were drawn, and recommendations for the system's use were given.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Blast effects						
Blast injuries						
Overpressure						
Attenuation						
Deflectors						
Fragmentation						
Body armor						
Shielding						
Explosive Ordnance Disposal						
Protectors						
Explosionproofing						